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Guidelines for Surface Water Quality

Vol. 1 Inorganic Chemical Substances

CHROMIUM

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Abstract

A literature survey was carried out on the toxic effects of chromium and chromium compounds on human health, aquatic life, plants and livestock. The information is summarized in this publication. From it, maximum chromium concentrations in water at which toxic effects will not appear are recommended.

Résumé

On a effectué une étude de la documentation portant sur les effets toxiques du chrome et de composés du chrome sur les humains, les organismes aquatiques, les plantes et le bétail. Ces données sont résumées dans cette publication. En se basant sur ces données, on propose des valeurs des concentrations maximales de chrome dans l'eau auxquelles on n'observe pas d'effets toxiques.

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RECOMMENDED WATER QUALITY OBJECTIVES FOR CHROMIUM

Use	Recommended objectives
Raw Public Water Supply	0.1 mg/L as total chromium for waters which will be subject to conventional treatment
Aquatic Life and Wildlife	
Aquatic Life	0.04 mg/L as total chromium. See footnote, page 6.
Wildlife	
Agriculture Water Supply	
Livestock Watering	1.0 mg/L as total chromium
Irrigation	0.1 mg/L as total chromium
Recreation and Aesthetics	
Recreation	0.1 mg/L as total chromium
Aesthetics	No recommended limit
Industrial Water Supplies	
Food Processing	0.1 mg/L as total chromium

Guidelines for Surface Water Quality

Vol. 1. Inorganic Chemical Substances. Chromium

Margaret C. Taylor, Stewart W. Reeder and Adrian Demayo

SOURCES, OCCURRENCE AND FORM

Natural Distribution of Chromium

Chromium is quite abundant in the earth's crust, ranking 21st among all elements with a concentration of 100 mg/kg, but is much less abundant in oceans, ranking only 48th with a concentration of 0.05 μg/L (Taylor 1964; Bowen 1966, p. 19f). In Canada, the concentration of "extractable" chromium in river water samples collected between 1972 and 1977 ranged between less than 0.0002 and 0.34 mg/L. Approximately 90% of the results were less than 0.02 mg/L (WQB 1978). Chromium is extracted from chromium ores of which the most important is chromite $\{(Fe,Mg)O, (Cr,Al,Fe)_2O_3\}$. The world production of chromite ore in 1973 contained approximately 2.05 million tonnes of chromium (Johnson 1976). The distribution of chromium in the environment and the transfers that take place between various parts of the ecosystem are shown schematically in Figure 1.

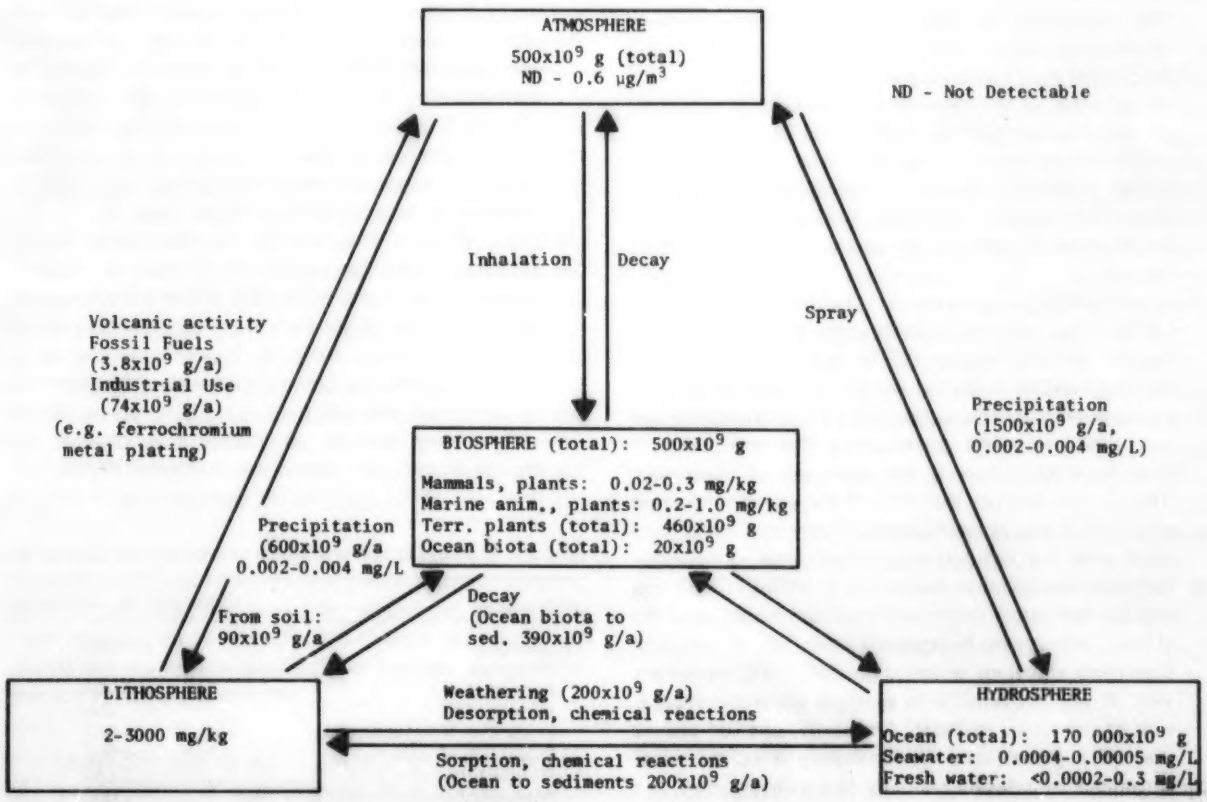

Figure 1. The global distribution of chromium and its transfer processes between various parts of the ecosystem (taken from NRC 1976, NAS 1974, Schroeder 1974).

Uses of Chromium

The main uses of chromium are in the metallurgical industry for the production of stainless, high-speed and other alloy steels, and in the refractory industry. Other uses are in the electroplating, metal finishing and leather tanning industries and in the production of fungicides, pigments, oxidants, and catalysts (Johnson 1976).

Pathways for Entering the Environment

Bertine and Goldberg (1971) estimated that 200 000 tonnes of chromium enter the environment as a result of weathering processes. In addition there are a series of anthropogenic sources through which chromium enters the environment:

1. Coal burning. The world coal production in 1974 was approximately 3 billion tonnes, of which half was used for energy production (McMullen 1976; Bertine and Goldberg 1971). The estimated chromium content of coal is 10 mg/kg (Bertine and Goldberg 1971). Therefore, the coal used for energy production contains approximately 30 000 tonnes of chromium. Bertine and Goldberg (1971) estimated that approximately 10% of this amount was released to the environment as fly ash. This amounted to 3000 tonnes of chromium being released annually to the environment as a result of the burning of coal.
2. Oil burning. The average concentration of chromium in oil was estimated at 0.3 mg/kg (Bertine and Goldberg 1971). The crude oil consumption in 1975 was 2.743 billion tonnes (Skinner 1976). Using the same approximation of 10% of the chromium content being released to the environment, the amount would be 800 tonnes per year.
3. Ferrochromium production. According to Sitting (1975), this was the major source of chromium emissions in the U.S.A. accounting for approximately 60% of total chromium emissions in that country. Even with emission controls, approximately 3.5% of the chromium used was lost to the environment. The production of ferrochromium alloys is the main use of chromium. Thus, if one assumes that 75% of the world production goes to this use, as much as 45 000 tonnes of chromium could enter the environment via this source.
4. Refractory production. According to Sitting (1975), this was another major source of chromium emissions in the U.S.A., accounting for approximately 9% of the total chromium emissions or approximately 1500 tonnes per year. It was not possible to estimate the world production of refractory material. Arbitrarily, one can assume that on a global scale approximately 4000 tonnes of chromium are released annually to the environment as a result of refractory production.
5. Cement manufacturing. Particulate emissions from cement manufacturing in the U.S.A. have been estimated to range between 116 and 171 kg per tonne with no controls. Emission controls can reduce this amount by 80% and 95% (EPA 1972). The world cement production in 1975 was approximately 695 million tonnes of which 95% was Portland cement (formulation is considered to be one-third shale and two-thirds limestone) (Stonehouse 1977; Goldberg 1976). Considering the chromium content of these two minerals, 90 and 11 mg/kg, respectively, it can be calculated that approximately 4500 tonnes can be lost to the environment in the particulate emissions with no controls or as little as 200 tonnes with emission controls. Canada's cement production in 1975 was 9.965 million tonnes or approximately 1.4% of the world's production. The corresponding chromium release to the environment ranged probably between 3 tonnes (with controls) and 63 tonnes (no emission controls).
6. Chromium steels. Sitting (1975) estimated that in the U.S.A. at a production level of 170 000 tonnes per year 470 tonnes of chromium entered the environment from this source. It is very difficult to find a global estimate for this source, but 1000 tonnes a year can be used as an approximation.
7. Metal plating. Sitting (1975) estimated that the daily load of chromium in the wastewater from the metal plating industry in the U.S.A. was of 25 tonnes or approximately 9100 tonnes per year. In Canada the corresponding figure is approximately 230 tonnes/year (EPS 1976). Again, it is very difficult to obtain a global estimate for the amount of chromium being released into the environment from this source, but a tentative value can be set at 20 000 tonnes per year.
8. Other sources. They include manufacturing of chromates and other chemicals, solid waste incineration, tanneries releasing Cr(III) in the effluent discharge, and oil well drilling where the drilling mud contains Cr(VI) as an anticorrosive. Although locally these sources can be very significant, on a global scale they are much smaller than the other sources listed above. In the U.S.A. they amount to slightly over 2% of total chromium emissions after controls (Sitting 1975).

Table 1. Pathways by which Chromium Enters into the Environment

Source	Global amount (tonnes/year)
Weathering	200 000
Anthropogenic sources:	
Burning of coal	3 000
Burning of oil	800
Production of ferrochromium	45 000
Production of refractory	4 000
Manufacturing of cement	2 400
Production of chromium steels	1 000
Metal plating	20 000
Other sources	1 500
Total anthropogenic sources	77 700

Forms of Chromium in the Environment

Several oxidation states are possible for chromium; the most important from industrial and environmental points of view are Cr(O)—metal, Cr(III)—chromic compounds, and Cr(VI)—chromates and dichromates.

Chromium (VI) is anionic in nature and is not strongly adsorbed by soil or particulate matter. This means that it is more mobile than Cr(III) and not so subject to sedimentation. Cr(VI) reacts strongly with oxidizable substances, usually organic molecules, and forms Cr(III). If the water contains very little organic material, Cr(VI) can remain as such for long periods of time. Under aerobic conditions, Cr(VI) is stable in natural waters. In anaerobic conditions, Cr(VI) is reduced to Cr(III), which at neutral or slightly alkaline pH, hydrolyzes and deposits chromium oxide (Cheremisinoff and Habib 1972).

Chromium (III) is a positively charged ion that has a strong tendency to form stable complexes with negatively charged inorganic or organic species. If there are no anionic species present, Cr(III) in neutral solutions can react with water to form colloidal hydrous oxides. Thus, it is very unlikely that much dissolved chromium will be present in aqueous solution. Chromium (III) is least soluble in the pH range covered by natural waters (NRC 1976, p. 22).

The distribution of a number of trace elements through a lake water column showed that the highest concentration of chromium and most of the other trace elements was in the hypolimnion (2.43 µg/L chromium was present in surface water, 2.25 µg/L at 1.0 metre, and 5.46 µg/L in the hypolimnion of Williams Lake, Washington) and this was thought to be due to interactions with bottom sediments (Funk *et al.* 1969).

No published work has been found in the literature and consequently nothing can be said about the formation and the presence of organochromium compounds in the environment, although it is possible that they form and are present in the ecosystem (Jewett *et al.* 1975).

Benes and Steinnes (1975) showed that the ratio of Cr(III)/Cr(VI) was affected by the amount of organic material and dissolved oxygen in water. Lake waters with high organic matter contained a greater proportion of Cr(III) and the highest proportion of hexavalent chromium was in the least polluted water.

Chromium (VI) in the presence of H_2S, produced by the decomposition of organic matter or by the discharge of industrial wastes, will be reduced to trivalent chromium, which will probably be adsorbed by the organic materials and removed from solution. Compounds bearing the sulphydryl group were found to reduce chromium. These compounds are probably not abundant enough in natural waters to affect chromium, but when Cr(VI) is taken up by aquatic organisms it may react with coenzymes bearing the group, thus inactivating them (Schroeder and Lee 1975).

Investigations on the release of some heavy metals in water from metal-rich lake sediments due to chelating agents NTA (nitrilotriacetic acid), EDTA (ethylenediaminetetraacetic acid), and TPP (sodium tripolyphosphate) were carried out by Barica *et al.* (1973), using both static and flow-through experimental systems. No significant changes in soluble chromium levels in water due to the presence of the chelating agents were detected in the flow-through tanks or static aquaria, or in the tissues of the midge (*Chironomus tentans*) held in the closed aquaria. Trivalent chromium concentrations in the crayfish (*Orconectes virilis* Hagen) were not significantly affected by the presence of chelating agents nor were the concentrations of Cr(III) in rainbow trout (*Salmo gairdneri* Richardson). This work seems to indicate that the presence of chelating agents in water would not release Cr(III) from contaminated sediments to the water or to aquatic organisms.

Trivalent chromium forms complexes with biological macromolecules, thus restricting its movement across biological membranes. It binds strongly to proteins and, in sufficient concentrations, forms cross linkages between carboxyl groups of different protein molecules. Chromates and dichromates have the ability to penetrate cell membranes to a much greater degree than Cr(III) compounds, this being one of the reasons why Cr(VI) is more toxic than Cr(III). Once inside a biological material, Cr(VI) is probably reduced to Cr(III) (NAS 1974).

Chromium and other trace elements have been shown to stabilize the ordered structure of RNA (ribonucleic acid) *in vitro*, but neither the exact function *in vivo* nor the valency of the chromium involved is known (NAS 1974).

There is little evidence to show that chromium accumulates in the food web (NRC 1976).

RATIONALE

Raw Public Water Supplies

Chromium in the Human Body

Chromium (III) is one of the essential elements of life and its function is related to the action of insulin (Buhler 1972).

Experiments with rats have shown chromium to be a dietary ingredient for the maintenance of normal glucose tolerance in mammals; as part of an organic complex it is probably active during the first steps of glucose metabolism, acting as a co-factor for the reaction of insulin with cell membranes (Vokal *et al.* 1975). It has also been shown that chromium is essential for cholesterol metabolism (Schroeder 1968). Its deficiency in the diet impairs glucose and cholesterol metabolism, leading to a higher blood level for both compounds. There is increasing evidence suggesting that chromium deficiency could be a basic factor in atherosclerosis (hardening of the arteries) (Schroeder 1974). The chromium content of different diets varies over a wide range, 10 to 400 µg/day, of which probably more than 95% originates in food; the rest comes from drinking water and a negligible amount from inhaled air (NAS 1974, p. 11ff; Clemente 1976). Chromium is poorly absorbed by the intestinal tract of mammals. Only 0.5% of an oral dose of Cr(III) and 2.1% of Cr(VI) was absorbed by man, and 2 to 3% Cr(III) and 3 to 6% of Cr(VI) by rats (NRC 1976, p. 99). Probably the most readily absorbed chromium compound along the digestive tract, 10 to 15%, is GTF (glucose tolerance factor), a natural complex of Cr(III) with several amino acids and nicotinic acid (NRC 1976), p. 66). This seems to be the only chromium compound which will pass the placental barrier, playing almost the role of a vitamin (NAS 1974, p. 38ff). The human body contains from approximately less than 6 to more than 12 mg chromium (Schroeder 1968) and the average excretion is 7.0 to 10 µg/day (NAS 1974, p. 28ff). The main excretion routes are the urinary tract, with at least 80% of the injected chromium, and the feces (NAS 1974, p. 39). The highest concentrations of chromium in the human body are found in the placenta, lungs, aorta and testis and the largest stores are in the skin, muscle, blood and fat (Schroder 1968).

Toxicity

Trivalent chromium tends to adsorb on fibres (food) or to precipitate as an insoluble form in the intestine. There is very little toxicity if it is ingested by mammals. The hexavalent form of chromium, Cr(VI), is more mobile than Cr(III), it is a stronger oxidizer, and diffuses readily into tissues to react and form Cr(III). Chromium (VI) also participates in the non-specific binding of important biological molecules, making it more toxic than Cr(III). Even low levels can inhibit respiratory chain activity by inactivating enzymes. Chromium (VI) also inactivates enzymes responsible for energy production from food (NRC 1976).

Several toxicity studies of chromium in drinking water are quoted in the NAS report (1974, p. 28). The data show that sublethal toxic concentrations of Cr(VI) in drinking water for mammals, including man, were in general greater than 25 mg/L. Chromium accumulation in tissues without any toxic effects was observed at a concentration of 5 mg/L of Cr(VI).

Although for essential metals the toxic level is approximately 40 to 200 times greater than the nutritional requirements (Buhler 1972, p. 13), in the case of chromium the toxic/therapeutic dose ratio for intravenously injected Cr(III) has been estimated at 10 000:1 (NAS 1974, p. 28ff). Occupational dermatitis is attributed to sensitization to Cr(VI) compounds present in various chromate-using industries. Usually the sensitivity test to Cr(VI) is carried out by using 350 to 1750 mg/L Cr(VI) solutions, although a hypersensitive patient reacted positively to 0.3 mg/L Cr(VI) (NRC 1976, p. 114).

Carcinogenesis and Mutagenesis

Different types of cancer were produced under experimental conditions by implantation of various Cr(VI) compounds in test animals (NRC 1976, p. 105ff). An increased risk of cancer in the respiratory tract has been linked to chromium compounds (NRC 1976, p. 105ff; Smith 1972). Lead chromate was shown to be carcinogenic when administered intramuscularly to rats (Furst *et al.* 1976).

Venitt and Levy (1974) indicated that hexavalent chromium compounds were mutagenic in tests with *Escherichia coli*, but that trivalent compounds did not induce mutation.

Recommended Limit for Raw Public Water Supplies

The chromium concentration in most surface waters in Canada is below 0.001 mg/L, the present detection limit of the analytical method used routinely for water analysis. Normal biological treatment (activated sludge) removes 40 to 80% of the chromium present in wastewater (Cohen 1977). Notice also that the usual chlorination of drinking water will oxidize any Cr(III) present to Cr(VI).

The United States Water Quality Criteria (EPA 1976, p. 37ff) recommended a limit of 0.05 mg/L for total chromium in drinking water as did the International Joint Commission (IJC 1976). *Canadian Drinking Water Standards and Objectives–1968* (NHW 1969) recommended a limit of 0.05 mg/L Cr(VI). In relation to the known toxic values, which are greater than 25 mg/L of Cr(VI), this limit is low (ration of 1:500). Only 0.5 to 2% of orally administered chromium is absorbed by humans. Also, in the case of chromium, an essential element of life, a case can be made for a minimum concentration in drinking

water to avoid the problems related to chromium deficiency (see section on chromium in the human body).

Based on these considerations, the limit recommended for total chromium $\{Cr(VI)$ plus $Cr(III)\}$ in drinking water supplies is 0.1 mg/L.

Aquatic Life and Wildlife

Aquatic Life - Toxicity

Reported toxicities for chromium vary considerably between groups of organisms and within groups of organisms; invertebrates and phytoplankton have been shown to be more sensitive than fish (Strik *et al.* 1975).

Macroinvertebrates have a wide range of tolerances to chromium. Work by Warnick and Bell (1969), using Cr(III) in soft water, showed 96 h LC_{50} ranging from 2.0 mg/L for *Ephemerella subvaria* (mayfly) to 64.0 mg/L for *Hydropsyche betteni* (caddisfly larva). Rehwoldt *et al.* (1973), using water of the same hardness (50 mg/L as $CaCO_3$), showed 96 h LC_{50} ranging from 3.2 mg/L (Amphipoda, Crustacea) to 58 mg/L for a caddisfly larva (Insecta). Temperatures and dissolved oxygen levels were fairly similar in the two series of experiments. Cairns and Messenger (1974) and Cairns *et al.* (1976) studied the response of different species of snails to heat shock after they had been exposed to heavy metals. The 48 h LC_{50} of Cr(VI) ranged from 0.4 mg/L for *Physa integra* to 42.0 mg/L for *Lymnaea emarginata* in a water with a hardness of 170 mg/L as $CaCO_3$. The snails were more susceptible to heat shock after being exposed to 0.2 mg/L Cr(VI). The mortality during exposure to this concentration of Cr(VI) without heat was similar to that of the controls. Biesinger and Christensen (1972), using the zooplankter *Daphnia*, gave a 3-week LC_{50} for Cr(III) of 2 mg/L and stated that 0.33 mg/L Cr(III) had a 16% impairment on reproduction. The chronic toxicity value was similar to that shown for *Salvelinus fontinalis* (brook trout) tested in water with the same hardness (45 mg/L as $CaCO_3$).

Studies with monoxenic cultures of three protozoans also indicated that a variety of tolerances existed between species. *Vorticella microstoma* was more sensitive to Cr(VI) than *Colpidium campylum* and *Opercularia* sp. by one order of magnitude. The growth of the most sensitive of the three protozoans *V. microstoma* was decreased to half the rate of the controls by 0.53 mg/L Cr(VI)(Sudo and Aiba 1973). There was a 50% inhibition of photosynthesis by some species of diatoms (Bacillariophyceae) at levels of 0.65 mg/L Cr(VI), very similar to those inhibiting the growth of the protozoan *V. microstoma* (Wium-Anderson 1974).

Some differences between the toxicities to fish of the two common valency forms of chromium, Cr(III) and Cr(VI), have been reported. Olson (1958) showed a higher mortality rate (>50%) and a lower growth rate for chinook salmon fingerlings (*Oncorhynchus tshawytscha*) in 0.2 mg/L Cr(VI) after 12 weeks exposure (water hardness, 70 mg/L) than in 0.3 mg/L Cr(III) or the controls, both of which had similar mortalities.

The application factor (AF) (see Preamble) for chromium has been shown to be very variable (Andrew *et al.* 1977). Benoit (1976) conducted sublethal studies on the growth and reproduction of brook trout (*Salvelinus fontinalis*) and growth of rainbow trout (*Salmo gairdneri*) using Cr(VI). The survival studies on rainbow and brook trout alevins showed Cr(VI) to be toxic at 0.35 mg/L in soft water (45 mg/L as $CaCO_3$) and pH 7-8. Rainbow trout were slightly more sensitive than brook trout. Growth was retarded during the first 12 months of exposure, but between 12 and 22 months the weights varied much less than those of the control fish. The difference in growth was not thought to be a major element in the laboratory tests, but it was pointed out that under natural conditions of feeding and environmental stress such as predators, the sublethal effects at this level may be important in affecting fish survival. There was only a small difference in sensitivities between acclimated and unacclimated alevins. Even though 99% hatching occurred at 0.35 mg/L Cr(VI), the numbers surviving were significantly less than the controls. The maximum acceptable toxicant concentration (MATC) was determined to be between 0.2 and 0.35 mg/L. The lower of the two concentrations agrees closely with work by Olson and Foster (1956) quoted in Benoit (1976).

Fathead minnows were less sensitive to Cr(VI) than rainbow and brook trout, but direct comparisons cannot be made, as the water hardness differed considerably between the two series of experiments. No significant effects were seen on the survival, egg production, and hatchability at 1.0 mg/L Cr(VI) (hardness 209 mg/L as $CaCO_3$). Early growth was affected in the first generation fish, as in the experiments with trout, but the final length and weight did not differ significantly from the controls. Lower concentrations 0.016, 0.063 and 0.25 mg/L had the same effect on early growth but not on survival (Pickering, personal communication).

The effect of hardness on the toxicity of chromium varies according to the type of organisms and the valency of the chromium. Tri- and hexavalent chromium were significantly more toxic in soft water (20 mg/L as $CaCO_3$) than in hard water (360 mg/L as $CaCO_3$) for fathead minnows (*Pimephales promelas*): 96 h LC_{50} was 5.07 mg/L Cr(III) in soft water, 67.4 mg/L Cr(III) in hard water; 17.6 mg/L

Cr(VI) in soft water, 27.3 mg/L Cr(VI) in hard water. The toxicity of Cr(III) was significantly different for bluegills (*Lepomis macrochirus*) in soft and hard water but not for Cr(VI) (Pickering and Henderson 1964). Tabata (1969) showed that hardness affected the toxicity of Cr(VI) for *Daphnia* sp. but not for carp (*Cyprinus carpio*), which is a fairly tolerant species. Bulkema *et al.* (1974) indicated that in hard water the toxicity initially increased above that in soft water but then decreased at 96 h and they proposed that this must be a reflection of the mechanism of toxicity.

There was some indication that young salmon were more tolerant to chromium when at their optimum temperature (10°C) than at lower temperatures (Olson and Foster 1957).

Pollutants are not always discharged to the receiving water at a continuous rate. Olson and Foster (1957) showed that the level of Cr(VI) maintained at 0.49 mg/L for only 1 of 7 days was less toxic than the equivalent dose of Cr(VI) at 0.07 mg/L maintained continuously over 7 days.

Some indication of one possible mechanism in the toxicity of Cr(VI) was given by Kuhnert *et al.* (1976). The effect of Cr(VI) on the activity of the enzyme Na/K-ATPase, which is involved in osmoregulation, was studied in the rainbow trout (*Salmo gairdneri*). Enzyme activity was significantly decreased in the kidney after exposure at 2.5 mg/L Cr(VI) for 48 h. The biochemical mechanism of the inhibition was not understood.

Bioconcentration of chromium is not thought to be an important factor in the aquatic environment. Fromm and Stokes (1962) showed that uptake could occur from water with low levels of chromium (1.3 µg/L). The uptake was proportional to the amount of chromium present in the water and was apparently passive in nature. Lucas *et al.* (1970) analyzed fish from Lakes Michigan and Superior and found an average of 1.0 mg/kg of chromium in whole fish tissue.

The maximum acceptable toxicant concentration lies between 0.2 and 0.35 mg/L Cr(VI) for young stages of brook trout. Other organisms such as plankton and some invertebrates had similar or greater tolerance to chromium. The level of 0.2 mg/L was obtained in experiments using soft water (45 mg/L as $CaCO_3$) as the diluent. The toxicity of chromium should be less in hard water areas.

Wildlife

Birds and mammals that consume fish should not be at risk if the recommended chromium limit for aquatic life is applied to waters which they frequent. No literature has been found to indicate that chromium accumulates through the freshwater food web.

Recommended Limit for Aquatic Life and Wildlife

Using a maximum acceptable toxicant concentration (MATC) of 0.2 mg/L Cr(VI) and a safety factor of 0.2, the recommended limit for aquatic organisms is 0.04 mg/L as total chromium.

The "real" safety factor is probably greater than 0.2 because chromium in unfiltered water would probably be present in both the hexavalent and trivalent forms. When levels are being considered for hard water (>120 mg/L as $CaCO_3$), it may be possible to use a smaller safety factor, but further deliberation is needed. Chromium has not been shown to bioaccumulate to any great degree, so the suggested level of 0.04 mg/L should provide adequate protection to fish and consumers of fish. See also footnote.

Water Supply for Livestock

Toxicity

Chromium is one of the essential elements in mammals, its functions being related to the action of insulin (Buhler 1972, p. 11; Mertz 1971, p. 197). The chromium concentration in wild and domestic animal tissues is approximately 0.15 to 0.2 mg/kg, which is higher than that in human tissue (0.02 to 0.03 mg/kg) (NRC 1976, p. 94).

Chromium can enter the body of an animal via the respiratory and digestive systems, and the skin. In setting limits for chromium concentration in water, the absorption via the digestive system is of particular interest.

Only 6% or less of orally administered chromium compounds were absorbed in studies with rats. Within this range Cr(VI) was absorbed to a greater extent than Cr(III) (NRC 1976, p. 99) and its toxicity was greater than that of Cr(III) compounds.

A paper by Sauter *et al.* (1976), which was received after the guideline had been written, estimated the maximum acceptable toxicant concentration for rainbow trout (*Salmo gairdneri*), the most sensitive of seven fish species tested, to lie between 0.051 (where no effect was seen) and 0.105 mg/L Cr(VI), the lowest concentration tested where a significant effect was noted. This work using soft water (hardness of 35 mg/L as $CaCO_3$) indicated that chromium may be more toxic than suggested by other research. As this possibility exists, a MATC of 0.105 and a safety factor of 0.2 gives a level of 0.02 mg/L total chromium for aquatic life. This may have to be considered in place of 0.04 mg/L total chromium until further research has been done.

Studies with rats and dogs have shown that water containing 5.0 to 6.0 mg/L Cr(VI) did not cause tissue damage or accumulation. Concentrations of 10 mg/L caused accumulation (NRC 1976, p. 102-3).

Recommended Limit for Livestock

Based on available experimental data and allowing for a safety factor, a maximum allowable concentration of 1.0 mg/L in the water supply of livestock is recommended. The same value of 1.0 mg/L was recommended in the U.S. by NAS/NAE (1973).

Water for Irrigation

Toxicity to Plants

Of the two common chromium forms in the environment, Cr(VI) and Cr(III), the former is more toxic to plants. In contact with soil, however, Cr(VI) is converted to Cr(III). Soluble Cr(III) in contact with soil is rapidly immobilized by the formation of insoluble hydroxides and oxides, sorption phenomena or by complexing, and thus becomes less available to plant uptake (NRC 1976, p. 84ff; CAST 1976, p. 25).

The chromium content of agricultural soils of Ontario ranged between 2.6 and 46.2 mg/kg, with an average of 14.3 mg/kg. Sandy soils had the lowest average concentration at 10.0 mg/kg while the clay soils had the highest average concentration at 22.3 mg/kg (Frank *et al*. 1976). Another survey carried out in some agricultural watersheds of southwestern Ontario found a concentration range of 10 to 95 mg/kg for chromium in soils and averages ranging from 49 to 55 mg/kg. The soils in Manitoba had a chromium concentration ranging from 10 to 33 mg/kg, with an average of 19.4 mg/kg (Mills and Zwarich 1975). Chromium concentration showed a good direct correlation with the clay and aluminum content of the soils (Whitby *et al*. 1978; Mills and Zwarich 1975).

Chromium is considered to be a toxic element for plants, interfering with the root uptake of some essential elements, e.g. calcium, potassium, phosphorus, and their transfer to the plant tops (NRC 1976, p. 84ff). Experimental studies with soybeans in water cultures showed that chromium concentrations of 0.5 mg/L reduced the culture yield (Turner and Rust 1971). Other studies summarized in a report from NRC (1976) showed that the toxic threshold chromium concentration in soil is 5.0 to 10 mg/kg depending on the chromium species, soil nature, and the type of culture.

Very little is known about the accumulation of chromium in soil. Studies of soil from below sludge and effluent disposal plants showed that, although there was some chromium enrichment, it was less than that for the other metals studied (Zn, Cd, Ni) (Lund *et al*. 1976, p. 330). One study (Wallace *et al*. 1976) showed that chromium toxicity increased when the soil contained the chelating agents EDTA and NTA.

Recommended Limit for Irrigation Water

A maximum allowable concentration of 0.1 mg/L for total chromium is recommended for irrigation waters. This is in agreement with the recommended limit in the U.S.A. (NAS/NAE 1973, p. 342).

Recreation and Aesthetics

Potable water supplies in recreational areas should comply with the level for drinking water of 0.1 mg/L total chromium. This level is also the one recommended for aquatic life and wildlife; therefore, it will be applied to any surface water used for recreation where camping and water contact sports occur.

Chromium has not been shown to bioaccumulate, so that sport fish should not contain levels of chromium which would be a hazard to human health.

Recommended Limit for Recreational Waters

The recommended limit for recreational waters is 0.1 mg/L total chromium.

Industrial Water Supplies

The only industry in which the concentration of chromium in the process water is significant is the food industry.

The general principle that the water which is incorporated in the final products should meet the same requirements as for drinking water applies here also.

Recommended Limit for Industrial Water Supplies

A maximum limit of 0.1 mg/L for total chromium $\{ Cr(III) + Cr(VI) \}$ is recommended for water which is incorporated in the final product in the food industry. This includes water used for the cooling of cans in the canning industry.

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